SPECIFICATION

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YAW CONTROL FOR AN AUTOMOTIVE VEHICLE USING STEERING ACTUATORS

Background of Invention

[0001] The present invention relates generally to a dynamic behavior control apparatus for an automotive vehicle, and more specifically, to a method and apparatus for controlling the lateral dynamics of the vehicle by controlling the front and/or rear wheel steer angle for the vehicle.

[0002] Dynamic control systems for automotive vehicles have recently begun to be offered on various products. Antilock braking systems (ABS) and traction control (TC) control tire slip ratios. More advanced dynamic control systems typically control the side slip angle and yaw response of the vehicle by controlling the tractive forces and/or braking torque at the various wheels of the vehicle. Side slip and yaw control systems typically compare the desired direction, yaw response, and lateral acceleration of the vehicle based upon the steering wheel angle, speed, and the direction of travel to an ideal (stable) vehicle model. By regulating the amount of braking torque and tractive friction at each corner of the vehicle, the desired path of travel and yaw rate may be maintained.

[0003] The yaw control systems mentioned above thus do not control the lateral or yaw response by controlling steering of the front wheels directly. Because of this, front independent control of steady state and dynamic response occurs. However, by having closed loop control over front or rear wheel steer angle, some tradeoffs between the vehicle steady state lateral dynamics and stability and the vehicle transient lateral dynamic response may be achieved.

[0004] It would therefore be desirable to provide a closed-loop control system that allows the transient lateral response and the steady state lateral gain and stability to be maintained, optimized, controlled, and/or tailored.

Summary of Invention

[0005] The present invention utilizes a steer-by-wire or smart road-wheel actuator system that allows a high level of control over the transient and steady state and dynamic response of the vehicle without the typical constraints of brake controlled vehicles. The present invention uses closed-loop electronic control of the steering wheel actuator to achieve this.

[0006] In one aspect of the invention, an automotive vehicle having a steering road wheel actuator includes a yaw rate sensor generating a yaw rate signal corresponding to the yaw rate of the vehicle and a steering wheel angle sensor generating a steering wheel angle signal. A feedback controller and feed forward controller are coupled to the steering road wheel actuator using inputs from the yaw rate sensor and the steering wheel angle sensor. The feed forward controller calculates a desired yaw rate in response to the steering wheel angle, and determines a corrected steering wheel input as a function of the desired yaw rate. The feedback controller then compares the actual and desired vehicle yaw rate, and controls the road wheel steering actuator in response to the corrected steering wheel input, the yaw rate and the modified steering wheel input to provide a steering angle that will result in a desired vehicle dynamic response.

[0007] In a further aspect of the invention, a method for controlling an automotive vehicle having a steering actuator includes measuring a steering wheel angle from a steering wheel angle sensor, determining a desired yaw rate in response to the steering wheel angle, determining a modified steering wheel input in response to the desired yaw rate, measuring a vehicle yaw rate from a yaw rate sensor, determining a corrected steering wheel input as a function of the desired yaw rate and the vehicle yaw rate, and controlling the steering actuator in response to the corrected steering wheel input.

[0008]

One advantage of the invention is that such systems may be easily implemented

into a steer-by-wire system. Another advantage of the invention is that great flexibility in controlling the vehicle lateral dynamic response independent of the steady state response is achieved. For example, a defined transient yaw response independent of the steady state yaw gain of the uncontrolled vehicle may be achieved. For example, the defined transient yaw response can be controlled such that it has critical yaw damping while the steady state gain is that of an under-steered vehicle (which is under-damped). The vehicle yaw gain thus reaches a maximum value at the characteristic speed then decreases as the speed increases further. This is generally considered a safer response. Also, the ability to increase the perceived linear range of the vehicle lateral response by independently changing the steering wheel to road wheel steer angle ratio. For example, road wheel angle/steering wheel gain can increase as lateral acceleration increases (in a closed-loop control) to extend the perceived line or range response of the vehicle. The vehicle yaw response increases as driver steering input increases for a given speed to provide improved vehicle response using closed-loop control. This can be tailored in software according to the desired vehicle driving/handling characteristics.

[0009] Other advantages and features of the present invention will become apparent when viewed in light of the detailed description of the preferred embodiment when taken in conjunction with the attached drawings and appended claims.

Brief Description of Drawings

[0010] Figure 1 is a front view of a motor vehicle illustrating various operating parameters of a vehicle experiencing a turning maneuver on a road surface.

[0011] Figure 2 is a top view of a motor vehicle illustrating various operating parameters of a vehicle experiencing a turning maneuver on a road surface.

[0012] Figure 3 is a block diagram showing a portion of a microprocessor interconnected to sensors and controlled devices, which may be included in a system according to the present invention.

[0013] Figure 4 is a control system block diagram in accordance with the present invention (only yaw control shown).

Detailed Description

[0014] A method according to the present invention is intended for use with yaw control systems implemented with electronically controlled or electrically actuated steering systems in automotive vehicles. However, the invention could easily be adapted for use in yaw control systems on other motor vehicles, such as watercraft and aircraft as well as on other vehicle systems, such as active tilt, rollover control or active suspension. While the example set forth herein is described with respect to a yaw rate signal, various lateral dynamic conditions may be used such as side slip angle, lateral acceleration and curvature response gain.

[0015] Referring now to Figures 1 and 2, various operating parameters and variables used by the present invention are illustrated as they relate to the application of the present invention to a ground based motor vehicle 10. Those skilled in the art will immediately recognize the basic physics represented by these illustrations, thereby make the adaptation to different types of vehicles easily within their reach. Lateral acceleration is represented by a_y, longitudinal acceleration is represented by a_x, yaw rate is represented by r, the steering wheel angle is δ, and road wheel angles u_1, u_2.

[0016] Referring now to Figure 3, stability control system 24 has a controller 26 used for receiving information from a number of sensors which may include a yaw rate sensor 28, a speed sensor 30, a lateral acceleration sensor 32, a roll rate sensor 34, a steering angle (hand wheel position) sensor 35, a longitudinal acceleration sensor 36, a pitch rate sensor 37, and steering angle position sensor 39. Steering angle position sensor 39 senses the position of the steered road wheels. Lateral acceleration, longitudinal acceleration, yaw rate, roll orientation and speed may also be obtained using a global positioning system (GPS). Based upon inputs from the sensors, controller 26 controls the road wheel steering angle. Depending on the desired sensitivity of the system and various other factors, not all the sensors 28-39 may be used in a commercial embodiment. Other factors may be obtained from the sensors such as the surface mu and the vehicle side slip angle, β.

[0017] Roll rate sensor 34 and pitch rate sensor 37 may sense the roll condition to be used with a rollover control system as an extension of the present application.

[0018] Steering control 38 may control a position of the front right wheel actuator 40A,

the front left wheel actuator 40B, the rear left wheel actuator 40C, and the right rear wheel actuator 40D. Although as described above, two or more of the actuators may be simultaneously controlled as one actuator. The actual positions are sensed by steering angle position sensor 39. For example, in a rack-and-pinion system, the two wheels coupled thereto are simultaneously controlled. Based on the inputs from sensors 28 through 39, controller 26 determines the vehicle dynamic condition and controls the steering position of the wheels. Controller 26 may also use brake control 42 coupled to front right brakes 44A, front left brakes 44B, rear left brakes 44C, and right rear brakes 44D. By using brakes in addition to steering control some control benefits may be achieved. For example, yaw control and rollover control may be simultaneously accomplished. That is, controller 26 may be used to apply a brake force distribution to the brake actuators in a manner described in U.S. Patent 6,263,261, which is hereby incorporated by reference. Or, conditions when one or the other is more effective.

[0019] Speed sensor 30 may be one of a variety of speed sensors known to those skilled in the art. For example, a suitable speed sensor may include a sensor at every wheel that is averaged by controller 26. Preferably, the controller translates the wheel speeds into the speed of the vehicle. Yaw rate, steering angle, wheel speed and possibly a slip angle estimate at each wheel may be translated back to the speed of the vehicle at the center of gravity (V_CG). Various other algorithms are known to those skilled in the art. Speed may also be obtained from a transmission sensor. For example, if speed is determined while speeding up or braking around a corner, the lowest or highest wheel speed may be not used because of its error. Also, a transmission sensor may be used to determine vehicle speed.

[0020] Controller 26 has a feedback and feed forward control system therein for modifying the steering input to the steering controller 38.

[0021]

Referring now to Figure 4, a feed forward/feedback control system 50 that may be implemented partially or fully in software in controller 26 is illustrated. Control system 50 receives the steering wheel angle δ_{driver} into a transfer function block 52. The transfer function block 52 outputs a desired yaw response $r_{desired}$ in response to the steering wheel angle measured by the steering wheel angle sensor. The desired yaw

rate $r_{desired}$ is applied to feed forward controller 53 which has a block 54 that has a transfer function for the yaw response of the base vehicle model. The output of block 54 of feed forward controller 53 is the modified steering wheel input δ_{mod} that will give the desired yaw response for the base vehicle model. The modified steering wheel input δ_{mod} is applied to a summing block 56 of the feed forward controller 53. The summing block 56 receives feedback as to a corrected steering wheel angle $\delta_{corrected}$ as will be further described below. The modified steering wheel angle δ_{mod} is combined with the corrected steering wheel angle $\delta_{corrected}$ and in this case is subtracted to form the actual commanded steering input u to vehicle 10. From the vehicle the measured yaw rate from the yaw rate sensor r_{actual} is obtained and applied to a summing block 58 of the feed forward controller 53. Summing block 58 receives the desired yaw rate $r_{desired}$ and the actual yaw rate r_{actual} and generates an error in yaw rate, Δr. The yaw rate desired is subtracted from the actual yaw rate to obtain the yaw rate error, Δr.

[0022] The feedback steering controller 55 receives the error in yaw rate signal Δr and generates the corrected road wheel steering input $\delta_{corrected}$. As mentioned above, the corrected road wheel steer angle is input to summing block 56. Controller 55 may use various types of input to determine the corrected steering wheel angle such as the error in yaw rate, the lateral acceleration, the vehicle speed, longitudinal acceleration, pitch rate, and/or the steering wheel angle position.

[0023] By providing a feed forward control, lag times can be minimized and the gain required in the feedback loop controller 55 can be minimized, thus achieving the ideal yaw response of the base vehicle model in an optimal, robust manner. The key feature of feedback control is that it provides the ideal yaw response regardless of physical variations within the vehicle; i.e. feedback control decreases the sensitivity of the vehicle yaw response to parameter variations such as vehicle loading, manufacturing variation, tires, and mileage degradation, etc.

[0024]

In operation, various types of steering control may be performed depending on the vehicle characteristics and the steering system. For example, as described above a front rack system can provide a desired change in the front steering angle temporarily while leaving the rear wheel steer angle unchanged. Of course, the steer angle of the

rear wheels could also be controlled to optimize the vehicle response to a driver steering input.

[0025] In a system having independently activated front wheels, the relative steering angle between the front wheels may be changed by steering control 38 without changing the position or controlling the position of the rear wheel. This may be done by independent control of the front wheels or simultaneous control of the front wheels.

[0026] In a system having independently activated rear wheels, the relative steering angle between the front wheels may be changed by steering control 38 without changing the position or controlling the position of the front wheels. This may be done by independent control of the rear wheels or simultaneous control of the rear wheels.

[0027] While particular embodiments of the invention have been shown and described, numerous variations and alternate embodiments will occur to those skilled in the art. Accordingly, it is intended that the invention be limited only in terms of the appended claims.